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Human Factors and Behavioral Science:

Membrane Keyboards and Human Performance

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This paper describes systematic human factors research in which typing performance using a membrane keyboard and using a conventional, full-travel keyboard were compared for subjects representing different levels of typing proficiency. Membrane switch technology has become increasingly popular in many consumer-oriented products because of its low production cost and design flexibility. However, the absence of familiar key travel associated with membrane switches removes an important, direct source of feedback to the user with respect to specific keystrokes. Hence, the conventional wisdom has been that membrane switches without key travel are unacceptable for such keyboard applications as typing tasks. The results of the research discussed here indicate that for nontouch typists there was little difference in performance between keyboards. For touch typists, performance with the conventional keyboard was initially much better than with the membrane keyboard. Rapid learning resulted in improvement in typing performance with the membrane keyboard—both within an experimental session and across sessions—such that the advantage of the conventional keyboard over tbe membrane one for touch typists was reduced substantially, although not completely. Future work will be aimed at measurement of the additional improvement in performance that may result from extended practice with better-designed membrane keyboards.

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I. INTRODUCTION

Membrane switch technology has become increasingly popular in consumer-oriented products such as pocket calculators and kitchen appliances. Application of this technology to the design of full-size, alphanumeric keyboards has resulted in products that differ markedly from conventional keyboards in terms of keystroke feedback to the user. Membrane switches usually consist of mechanical contacts on two layers of material, separated by a nonconductive third layer of material (see Fig. 1). The upper, membrane layer is usually a thin polyester material with flexible conductors applied to its underside. Graphics may be silk-screened on this surface or on a second surface placed on top of the membrane layer. The substrate may be either a printed circuit board with conductors or a flexible film with printed conductors. This is usually mounted on a rigid, smooth surface. The spacer layer is an insulating material that separates the membrane and substrate layers by 5 to 7 mils. It has holes through which the upper, flexible layer may be depressed, causing contact closure. When pressure on the membrane layer is removed, the resilient, flexible membrane breaks contact with the substrate and returns to its original position.

Membrane switch technology bas become popular for several reasons. Its production costs are low because there are no key-plunger mechanisms. It also affords considerable design flexibility in terms of panel layout, "key" size and shape, and graphic labels. Good switch enclosure can also be assured for hostile environments and for protection against dust accumulation, spills, and vermin infestation. Easy cleaning of the upper surface is also an advantage associated with membrane switch technology.

Although there are several technical advantages of membrane switches, there are potential user-related problems when this technology is applied to full-size keyboard design. First, familiar key travel is absent as a source of keystroke feedback to the user. Second, high actuation forces are often used with membrane switches to prevent accidental switch closure that may occur from pressure exerted by hands or fingers in a resting position on the contact area of the switcb. Finally, the actual contact area ("sweet spot") of the switch often is indiscriminable for the user, compared with traditional mechanical switches that use key caps on top of key-plunger mechanisms.

Despite these disadvantages, membrane switch technology is currently being introduced into the design of full-size keyboards because of its considerable cost advantages. There is little question that membrane switches may be used successfully for simple on-off function keys. There is, however, considerable doubt about the use of this technology for keyboard tasks such as typing because of the assumed

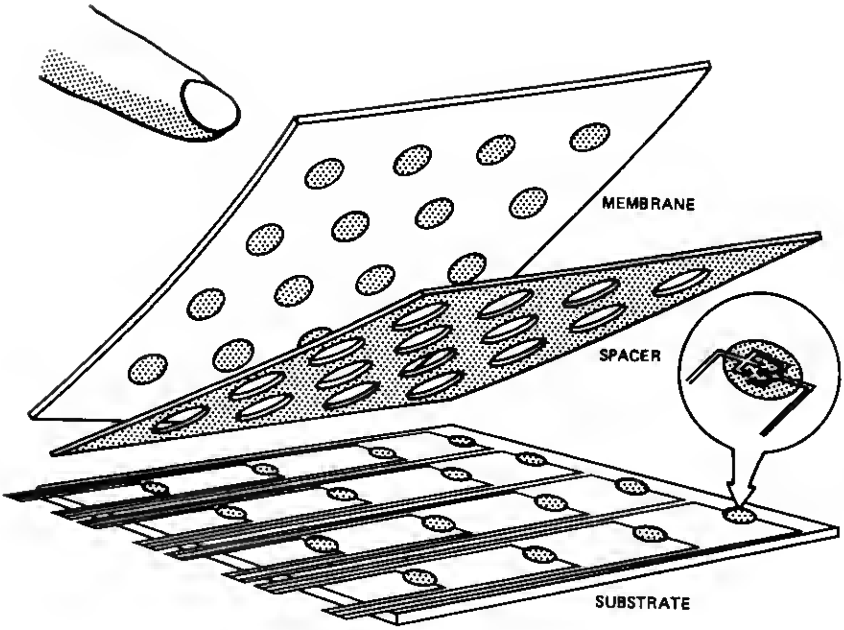

Fig. 1—Membrane switch technology.

importance to the user of key-travel feedback associated with individual keystrokes. Despite an absence of empirical evidence to support this claim, the conventional wisdom has been that membrane keyboards cannot be used as high-speed data- or text-entry devices.

Systematic human factors research was thus undertaken to determine whether performance using membrane keyboards differs from that using a conventional, full-travel keyboard. It was expected that large performance differences between keyboards would be present initially, but that with practice these performance differences might be reduced. Thus, this research was designed to provide subjects with several experimental sessions using each keyboard. It was also hypothesized that typing skill would be directly related to initial performance differences between keyboards and, perhaps, to the speed of learning to use the membrane keyboard. Specifically, it was expected that better touch typists would initially show greater performance differences between the membrane and conventional keyboards than less skilled touch typists because of the greater familiarity of the better touch typists with conventional keyboards. However, it was also possible that skilled touch typists would demonstrate greater transfer of typing skills to a novel keyboard and, hence, would learn to use the membrane keyboard more rapidly than less skilled touch typists.

Unskilled, nontouch typists, who tend to look at the keys as they are struck, were expected to sbow little difference in performance between membrane and conventional keyboards. A witbin-subject design with multiple sessions was used so that each subject would serve as his/her own control. This design also facilitated direct comparisons of typing performance on the membrane and conventional keyboards over time.

II. METHOD

2.1 Subjects

Twenty-one subjects (17 females and 4 males) participated in this study. Subjects were either employees of Bell Laboratories or volunteers from the local community. Volunteers were paid nominally for their participation in the study. Subjects varied in their typing ability and their average typing time per week.

2.2 Facilities and equipment

Two commercially available keyboards were used in this study. The presence or absence of familiar key travel associated with each keystroke was the most distinguisbable difference between these keyboards. One keyboard was considered a conventional keyboard in terms of key travel (about 100 mils to contact and an additional 50 mils to bottoming out), average actuation force (68 grams or 2.4 oz.), keytop size (450 mils diameter), and interkey spacing (750 mils, center-to-center). The other keyboard was a flat membrane keyboard with virtually no key travel. The average actuation force was 82 grams or 2.89 oz. A 1-mil-thick grid overlay delineated individual "keys." The "keytop" diameter size was about 600 mils with interkey spacing of 750 mils, center-to-center. Botb keyboards had a QWERTY layout of alphanumeric keys and also a DELETE key that permitted subjects to make corrections. Audio feedback associated with each keystroke was achieved upon "key" depression with the key plunger mechanism for the conventional keyboard (an audible "click") and with an internal audio tone generator for the membrane keyboard.

Hardware and software interfaces were developed to permit on-line experimentation and data collection using these keyboards. Both keyboards were interfaced witb a MINC-11/03 (DEC) minicomputer via an RS-232 port. The output from the keyboard was displayed simultaneously on a 9-inch video monitor placed directly in front of the subject behind the keyboard and on a VT-105 (DEC) display in front of the experimenter (see Fig. 2).

The study was conducted on-line with the MINC computer displaying appropriate prompts (e.g., "type text") to the subject prior to each of the experimental tasks. Three types of data were collected during each task: the actual characters displayed on the monitor, the actual

Fig. 2—Experimental setup.

characters typed by the subject (including deletions and corrections), and each interkeystroke time interval.

2.3 Experimental tasks

Each subject participated in six sessions, three with the membrane keyboard and three with the conventional keyboard. Three types of tasks were used twice during each session: dialing telephone numbers, typing text, and answering questions. The typing-text and dialing-numbers tasks were viewed as experimental tasks, while the answering-questions tasks were viewed as practice tasks. Each experimental task was considered a "trial" so that there were two trials for each type of experimental task per session. In addition, there were two sets of questions for the practice tasks per session. The stimulus materials for each of these tasks were placed on a typing stand to the right of the keyboard and monitor.

Each "dialing" task consisted of 30 seven-digit phone numbers that were to be dialed from the keyboard. Two different lists of numbers were used for each of three sessions with a given keyboard, for a total of six different lists. The two lists used for each of the first, second, and third sessions with the conventional keyboard were identical to those used for the respective sessions with the membrane keyboard. Hence, direct comparison of performance using the two keyboards for a particular session was possible.

Each "typing text" task consisted of a paragraph from a standard

typing textbook that is used to train and assess typing speed.[1] The paragraphs were of comparable typing difficulty, based upon syllabic intensity ratings. These ratings reflect the average number of syllables per word and are traditionally used to assess the typing difficulty of textual material.[1] As with the phone number list, two different paragraphs were used for each session with the given keyboard, for a total of six different paragraphs. The two paragraphs for each of the first, second, and third sessions for the conventional keyboard were identical to those used for the respective sessions with the membrane keyboard. Hence, direct comparison of performance between keyboards for a particular session was possible. These tasks were considered the most critical ones with respect to the major objectives of tbis study.

Each answering-questions task consisted of a few questions on a general topic (e.g., favorite sport and how it is played, most recent vacation activities). Subjects answered these questions using the conventional or the membrane keyboard. Two different sets of questions were used during each session, for a total of 12 different sets. Tbis task was primarily designed to provide a structured exercise by which the subject would gain experience using each keyboard.

2.4 Procedure

At the beginning of each session, a standard 3-minute typing test was given to each subject. This test was conducted using an IBM Selectric typewriter. Following this test, each subject completed six tasks on either the conventional or the membrane keyboard. The tasks were administered in the following order: dialing numbers, typing text, answering questions, answering questions, typing text, dialing numbers. This order of tasks allowed the subject about one-half to three-quarters of an hour of practice on each keyboard (e.g., the answering-questions trials) in between the two dialing-numbers and typing-text trials. This order of tasks, then, maximized observation of practice effects over trials within a session but also minimized warm-up and fatigue effects on the critical typing-text trials. There were also four general questions that were answered as a warm-up exercise at the beginning of the first session with each type of keyboard.

Each subject completed three sessions with one keyboard and then three sessions with the other keyboard. Sessions took place on consecutive (or nearly consecutive) days, one session per day. At the conclusion of each session, subjects completed a questionnaire that probed their rating of various features of each keyboard. At the conclusion of the third session with each keyboard, another typing test with an IBM Selectric typewriter was administered to assess cbanges in typing performance over the course of a session. Thougb these changes in performance on the IBM Selectric are not reported bere, they helped

determine the typing skill classification for each subject. Biographical data regarding touch typing ability, weekly amount of time typing, and prior use of membrane switches were also obtained.

2.5 Typing groups

Subjects were categorized according to their typing ability based upon two criteria. First, assessment was made of their use of touch typing tecbniques in which all ten fingers and "home row" positioning of the fingers are used. Second, tbeir average gross words per minute (WPM) on the eight typing tests given on an IBM selectric typewriter during the six experimental sessions was computed (i.e., the typing tests preceding each session and the test following the third session with each keyboard). These post-hoc criteria resulted in the following five categories of typing proficiency (see Table I): excellent touch typists (more than 60 WPM), good touch typists (50–60 WPM), fair touch typists (40–49 WPM), poor touch typists (26–39 WPM), and non-toucb typists (16–25 WPM). There were 3, 5, 5, 4, and 4 subjects in these respective typing groups, for a total of 21 subjects.

The order in which keyboards were used by subjects was counter-balanced within each touch typing group through random assignment of subjects to one of the two possible keyboard orders. This balancing scheme for keyboard order was limited by the fact that the post-hoc categorization of subjects into typing groups resulted in an unequal number of subjects per group. Hence, to the extent possible, half the subjects in each touch typing group experienced the membrane key-board first (total = 9 subjects) while the remainder of each toucb typing group used the conventional keyboard first (total = 8 subjects). Also, by chance, all of the subjects wbo were categorized post hoc as nontouch typists used the membrane keyboard first. Hence, for the nontouch typing group, there was no variation across subjects in keyboard order.

2.6 Experimental design

Typing Group (5 levels) was the major between-subject factor. Order of keyboards (2 levels) was considered a minor between-subject factor. Analyses using this factor across the touch typing groups were not

Table I—Number of subjects per typing group

Touch Typing Group	Gross Words Per Minute	Total Number	Membrane First	Conventional First
Excellent	>60	3	2	1
Good	50–60	5	3	2
Fair	40–49	5	2	3
Poor	26–39	4	2	2
Non	16–25	4	4	0

reported since the number of subjects per unit of analysis was extremely small, making interpretation of results complex. In addition, there was no variability across the order variable for the nontouch typists, and the basis for estimating the variance attributable to keyboard order for this group was inadequate. Within-subject factors included keyboards (2 levels), sessions (3 levels), and within-session trials (2 levels). Separate analyses were conducted for tbe different types of experimental tasks (dialing and typing text). The data from the answering-questions trials were not analyzed.

III. RESULTS

Several dependent measures were computed for each subject for the dialing and typing tasks. These measures were based upon the speed and/or accuracy of performance using both the conventional and membrane keyboards. Of particular importance to this study were the performance differences between the two keyboards for tbe various typing groups. Hence, difference scores and percent difference measures were also computed for each subject, and mixed-factor analyses of variance (ANOVAs) were performed. In addition, for the typing tasks the speed and accuracy data were combined to compute each subject's average words per minute, a throughput measure of performance.

3.1 Dialing results

For each dialing task, the number of phone numbers dialed incorrectly and not subsequently corrected was computed. This measure included both misdialed digits as well as insufficient or additional digits per phone number. However, if a subject corrected a dialing error through use of the DELETE key, the resultant pbone number was considered correct. There were 30 phone numbers per dialing task. On a few trials, a subject either omitted a phone number or redialed a phone number, a mistake no doubt attributable to the experimental set-up. These omitted or redialed phone numbers were not scored as dialing errors. Hence, the percent error rate for dialing phone numbers for each subject was computed from these data, and an ANOVA was performed.

As shown in Table II, the error rate for the dialing tasks was low for all groups using either the conventional or the membrane keyboard (less than 3 percent). The ANOVA indicated no significant difference in dialing accuracy as a function of keyboard or typing group ($p = 0.259$ and $p = 0.720$, respectively). There were also no significant effects when difference scores between keyboards were computed for each subject and served as the unit of analysis.

Table II—Percent error rate for dialing tasks*

Keyboard	Touch Typing Group Excellent	Good	Fair	Poor	Non
Membrane	1.11	2.66	2.01	2.50	1.30
Conventional	2.61	2.85	1.88	2.78	1.52
Mean	1.86	2.98	1.95	2.64	1.24

*Error rate is for uncorrected errors.
Each dialing task has 30 phone numbers.

3.2 Dialing summary

Accuracy of dialing performance did not vary as a function of keyboard used or typing proficiency level. Given the simplicity of the task, relative to typing text, this result is not surprising. The data do, however, provide an anchor point for comparison of performance between the two keyboards as task complexity increases.

3.3 Typing results

For each typing task, the number of "words in error" that remained after the subjects' corrections was computed according to traditional methods of scoring typing tests.[2] Hence, an incorrect letter(s), a missing letter, a letter reversal, a punctuation error, and/or a spacing error were all scored as a "word in error." The six passages, while equated in difficulty based upon the traditional syllabic intensity level, varied somewhat in the total number of words per passage (number of words per passage, where 5 character spaces equals 1 word, were: 64, 57, 79, 77, 73, 84).

3.3.1 Typing accuracy

Typing accuracy was measured in terms of both uncorrected errors and corrections. As shown in Table III, the total number of words in error was quite small (range: 1.8 to 4.5 words). The ANOVA did not indicate a reliable difference for this measure among typing groups or between keyboards. There was, however, a significant trial effect [$F(1,16) = 20.01$, $p < 0.0005$], with errors declining as a function of practice (4.2 vs. 2.7 errors).

Unlike standard typing tests, subjects were permitted to correct errors during the typing tests through use of the DELETE key. An ANOVA was performed on the number of corrections made by subjects during each typing task. The results indicated significant effects of keyboard [$F(1,16) = 5.27$, $p = 0.035$] and of session [$F(2,32) = 3.63$, $p = 0.038$]. In general, more corrections were made using the membrane keyboard than using the conventional keyboard (4.61 vs. 3.14), as shown in Table IV. Also, more corrections were made in the second

Table III—Average words typed in error

Keyboard	Touch Typing Group: Excellent	Good	Fair	Poor	Non
Membrane	1.99	1.83	3.77	3.79	4.54
Conventional	2.56	4.13	3.90	3.13	3.79
Mean	2.28	2.98	3.83	3.63	4.17

Table IV—Average number of corrections for typing tasks

Keyboard	Touch Typing Group: Excellent	Good	Fair	Poor	Non
Membrane	3.22	4.57	6.10	6.13	2.38
Conventional	4.00	2.47	3.83	2.96	2.67
Mean	3.61	3.52	4.97	4.54	2.52

and third sessions than in the first session, even though there was no reliable session difference in typing accuracy (i.e., uncorrected words in error). This session effect for number of corrections may be related to passage length; the average passage length was shorter for the first session (61 words) than for later sessions (78 words), and the probability of making a typing error increases as passage length increases. There was also a significant interaction between keyboard and trial factors [$F(1,16) = 5.48$, $p = 0.033$]. This interaction reflected a more dramatic practice effect (i.e., decline in errors corrected) for the membrane keyboard than for the conventional one.

3.3.2 Typing speed

The total typing time for each trial was also computed and an ANOVA was performed. The results indicated, as expected, a significant effect of typing group [$F(4,16) = 6.94$, $p = 0.002$]. As expected, typing speed varied directly with typing proficiency level, as shown in Table V. There was also a significant keyboard effect [$F(1,16) = 64.7$, $p < 0.005$]. Typing performance was somewhat faster with the conventional keyboard than with the membrane keyboard (130 seconds vs. 171 seconds).

Though there were other reliable effects related to the trial and session factors on speed of typing, it should be noted that, as with the typing accuracy data, variation in passage length (57 to 84 words) for the six test passages could readily have contributed to differences in typing time per trial and/or session.

3.3.3 Differences between keyboards in typing speed

Because of the variation in passage length, ANOVAs were performed on the difference in typing time between the two keyboards for

Table V—Average time for typing tasks (in seconds)

	Touch Typing Group				
Keyboard	Excellent	Good	Fair	Poor	Non
Membrane	134.1	143.5	166.8	193.6	213.1
Conventional	97.0	101.4	106.7	149.0	169.9
Mean	115.5	122.5	136.7	171.3	206.2

corresponding trials. Each difference score was thus based upon the same passage typed on each keyboard.

The ANOVA results indicated significant effects of both the session [$F(2,32) = 3.68$, $p = 0.036$] and the trial [$F(1,16) = 27.0$, $p < 0.0005$] factors. These findings reflect practice effects both across and within sessions. There was also a significant interaction between trial and session factors [$F(2,32) = 3.5$, $p = 0.042$], as shown in Table VI. This interaction was attributable to larger practice effects between trials during the first two sessions, compared with those during the last session. This practice or learning effect within a session is based primarily upon greater improvement in typing speed using the membrane keyboard, compared with that using the conventional keyboard.

The main effect of typing group for this measure approached significance ($p = 0.084$). The largest speed difference between the keyboards occurred for the fair touch typists and the least difference occurred, as expected, for the nontouch typists. Post-hoc analyses (Duncan's Multiple Range Test) indicated that the difference in typing speed between the two keyboards for the fair touch typists was reliably greater than that for all groups other than the poor touch typists ($p < 0.05$), and the difference score for the nontouch typists was reliably less than that of all the touch typing groups ($p < 0.05$).

3.3.4 Words per minute

Perhaps the most relevant measure for the assessment of typing performance is the calculation of each subject's typing ability in terms of words per minute (WPM). This measure reflects a throughput measure of performance that takes into account both speed and accuracy:

$$\frac{\text{number of words typed} - \text{number of words in error}}{\text{total time in minutes}}$$

It was obviously expected that WPM for the typing tasks would vary directly with the typing group categories since this measure for a similar typing task was the basis for classifying individuals into typing groups. It was also likely that the experimental set-up per se might result in lower WPM scores than those calculated from the standard

Table VI—Average typing time difference between membrane and conventional keyboards (in seconds)

	Touch Typing Group				
	Excellent	Good	Fair	Poor	Non
Session 1					
Trial 1	48.5	61.5	89.2	74.6	25.1
Trial 2	24.2	27.0	52.8	40.1	11.6
Session 2					
Trial 1	59.0	67.2	62.9	52.5	32.3
Trial 2	30.4	45.9	50.8	34.0	7.9
Session 3					
Trial 1	39.0	20.6	56.2	42.4	6.1
Trial 2	21.7	32.8	48.7	23.6	16.5
Mean	37.1	42.5	60.1	44.5	14.0

typing tests given to each subject since many touch typists were unfamiliar with an electronic keyboard attached to a visual display.

The ANOVA on WPM scores confirmed these predictions. The main effects of all four experimental factors were significant: typing group [$F(4,16) = 9.45$, $p < 0.0005$]; keyboard [$F(1,6) = 58.7$, $p < 0.0005$]; session [$F(2,32) = 24.6$, $p < 0.0005$]; and trial [$F(1,16) = 23.0$, $p < 0.0005$]. Practice improved performance both across sessions and between trials within a session. The poor and nontouch typing groups differed reliably from the other groups, as shown in Table VII. Performance was also significantly better for the conventional than the membrane keyboard (35.4 vs. 25.9 WPM). However, a reliable interaction between keyboard and typing group [$F(4,16) = 3.74$, $p = 0.025$] indicated that the keyboard effect was attributable to performance differences for the excellent, good, and fair touch typing groups. Post-hoc analyses showed tbat performance differences between keyboards were not reliably different ($p > 0.05$) for either the poor touch typists or the nontouch typists.

The trial factor interacted significantly with the keyboard factor [$F(1,16) = 1.7$, $p = 0.003$] and with the session factor [$F(2,32) = 4.31$, $p = 0.022$]. The improvement with practice across trials within a session was somewhat greater with tbe membrane keyboard than with the conventional keyboard. Also, the degree of improvement between trials within a session diminished as practice (i.e., number of sessions) increased, with the largest difference between trials occurring, as expected, during the first session.

3.3.5 Differences between keyboards in words per minute

The relative, rather than the absolute, performance of each subject using the two keyboards was of primary concern in this study; hence,

Table VII—Average words per minute for typing tasks

Keyboard	Touch Typing Group: Excellent	Good	Fair	Poor	Non
Membrane	32.1	30.4	25.4	22.1	20.2
Conventional	43.4	43.0	39.0	28.9	21.6
Mean	37.7	36.7	32.2	25.5	20.9

the percent difference in WPM using the two keyboards was computed to evaluate the relative advantage of the conventional keyboard over the membrane keyboard:

$$\frac{\text{WPM on conventional} - \text{WPM on membrane}}{\text{WPM on conventional}} \times 100.$$

This measure was computed for each subject for each typing task such that each difference score was based upon the same paragraph of text using each keyboard.

The ANOVA based upon this measure indicated significant main effects of the session [$F(2,32) = 3.57$, $p = 0.04$] and the trial [$F(1,16) = 17.6$, $p = 0.001$] factors. Both the session and trial effects reflected a decrease with practice in the percent difference in WPM between keyboards. The third session differed reliably from the first and second sessions (19.0% vs. 26.6% and 24.3%, respectively). The performance difference between keyboards was also reduced from the first to the second trial within a session (26.5% to 20.1%). The main effect of typing group approached significance [$F(4,16) = 2.93$, $p = 0.054$]. The conventional keyboard had relatively little advantage over the membrane keyboard for the nontouch typing group (6.5%), while this advantage was much more pronounced for the other touch typing groups (excellent = 26.0%, good = 25.5%, fair = 34.2%, and poor = 21.7%). The pattern of results for this measure for eacb group is depicted in Fig. 3. The difference between the touch typing groups and the nontouch typing group as well as the effect of practice are readily apparent. For the nontouch typists there is virtually no advantage of tbe conventional keyboard over the membrane keyboard; for one trial, subjects even performed slightly better with the membrane keyboard than with the conventional keyboard. For the touch typing groups the performance with the conventional keyboard was initially much better than that with the membrane keyboard. However, the percent advantage of the conventional keyboard over the membrane one was reduced substantially, although not completely, as a function of limited practice.

It is noteworthy that, despite this rapid learning function, the excellent touch typists appear to "forget" during the interval between sessions what they learned during a session. This phenomenon is

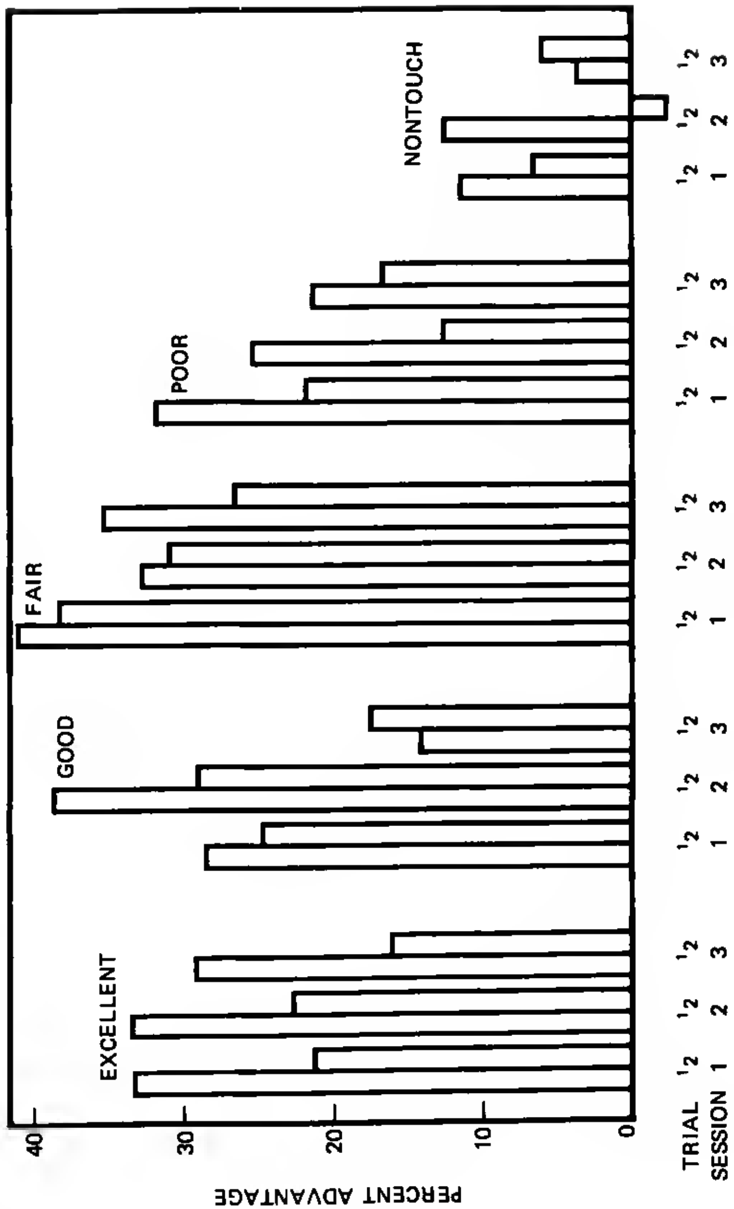

Fig. 3—Average words per minute advantage of conventional keyboard over membrane keyboard as a function of experience and touch typing group.

depicted by the larger advantage of the conventional keyboard over the membrane keyboard for the first trial of a new session, compared with that for the last trial of the prior session. This result, however, is less surprising when biographical data from these subjects are examined; these data indicate that the excellent touch typists spend about 28 hours per week using a conventional keyboard. These subjects were returning between sessions to a keyboard similar to the conventional one used here, and this activity between sessions may have produced retroactive interference, resulting in their forgetting what they had previously learned with respect to the membrane keyboard. Hence, the advantage of the conventional keyboard over the membrane keyboard was most pronounced at the beginning of each new session.

3.4 Typing summary

For the typing tasks, there was evidence of rapid learning that resulted in improved performance on the membrane keyboard, relative to the conventional one, both within and across sessions. Practice effects were found on measures of both speed and accuracy. Keyboard effects were also evident. Performance was faster on the conventional keyboard than on the membrane one. Differences in speed between the two keyboards were most pronounced for the fair touch typists and virtually nonexistent for the nontouch typists. Also, more corrections were made with the membrane keyboard than the conventional one, especially at the beginning of a session.

When speed and accuracy data were combined to produce the WPM measure, practice effects were still evident. Keyboard effects were also evident, but primarily for the excellent, good, and fair toucb typists. When the relative difference between keyboards in throughput performance was examined (i.e., percent advantage in terms of WPM), keyboard effects were apparent for the touch typing groups. Performance with the conventional keyboard was initially much better than it was with the membrane keyboard for touch typists. There was, however, rapid learning to use the membrane keyboard such that the advantage of the conventional keyboard, relative to the membrane one, was reduced substantially, although not completely. For nontouch typists there was virtually no advantage of the conventional keyboard over the membrane one. Finally, "forgetting" between sessions for excellent touch typists appears attributable to their customary use of another conventional keyboard during the interval between sessions.

IV. SUMMARY

The purpose of this study was to compare performance using a membrane keyboard with that using a conventional keyboard for

different levels of typing proficiency. In general, the results indicate little difference in performance between keyboards for nontouch typists. For touch typists the results demonstrate better performance on conventional keyboards than on membrane ones. However, the results also demonstrate rapid learning to use the membrane keyboard. With just three hours of experience, performance differences between keyboards for touch typists reflected, at worst, a 27-percent advantage of the conventional keyboard over the membrane one and, at best, a 16-percent advantage.

These results provide human factors evidence that the difference in performance using membrane and conventional keyboards is much smaller than might be expected, given the absence of key travel feedback associated with each keystroke. Moreover, touch typists who are familiar with conventional, "full-travel" keyboards quickly learn to use membrane keyboards. For most touch typists, there remains an advantage for the conventional keyboard over the membrane keyboard after a limited exposure (only about three hours) to the novel keyboard.

These results are encouraging in terms of the application of membrane switch technology for some keyboard tasks. First, the particular membrane keyboard tested in this study does not necessarily represent an optimal membrane keyboard. Features of this particular keyboard that were identified as bothersome to subjects will be used in guiding the design of membrane keyboards for future evaluation. Second, extended practice with membrane keyboards may diminish residual differences in performance between conventional and membrane keyboards. Given the cost advantages and design flexibility afforded by membrane switch technology, such avenues may be well worth pursuing in the design of new products.

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